Hubble Space Telescope Multi Layer Insulation Failure Review Board Results

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Materials Engineering Branch

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Overview

- Hubble Space Telescope Observations
- Damage Mechanism Investigation
  - Retrieved Specimen Failure Analysis
  - Simulated Environmental Exposures
- Replacement Material Selection
- Conclusions

Acknowledgments

- HST MLI Failure Review Board
  - NASA- GSFC, JPL, LeRC
  - Lockheed-Martin, Swales Aerospace
- Test Team
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HST Observations

- Images
  - SM1 Observations
  - SM2
    - Observations
    - Damage Map
  - SM2 Aft Bulkhead Discoloration
  - Retrieved Specimens
- Orbital Environment

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Hubble Space Telescope

- Deployed April 25, 1990
  - Altitude -- 598 km (320 nmi)
  - 28.5° orbit inclination
- First Servicing Mission
  - December 1993 (3.6 years)
- Second Servicing Mission
  - February 1997 (6.8 years)

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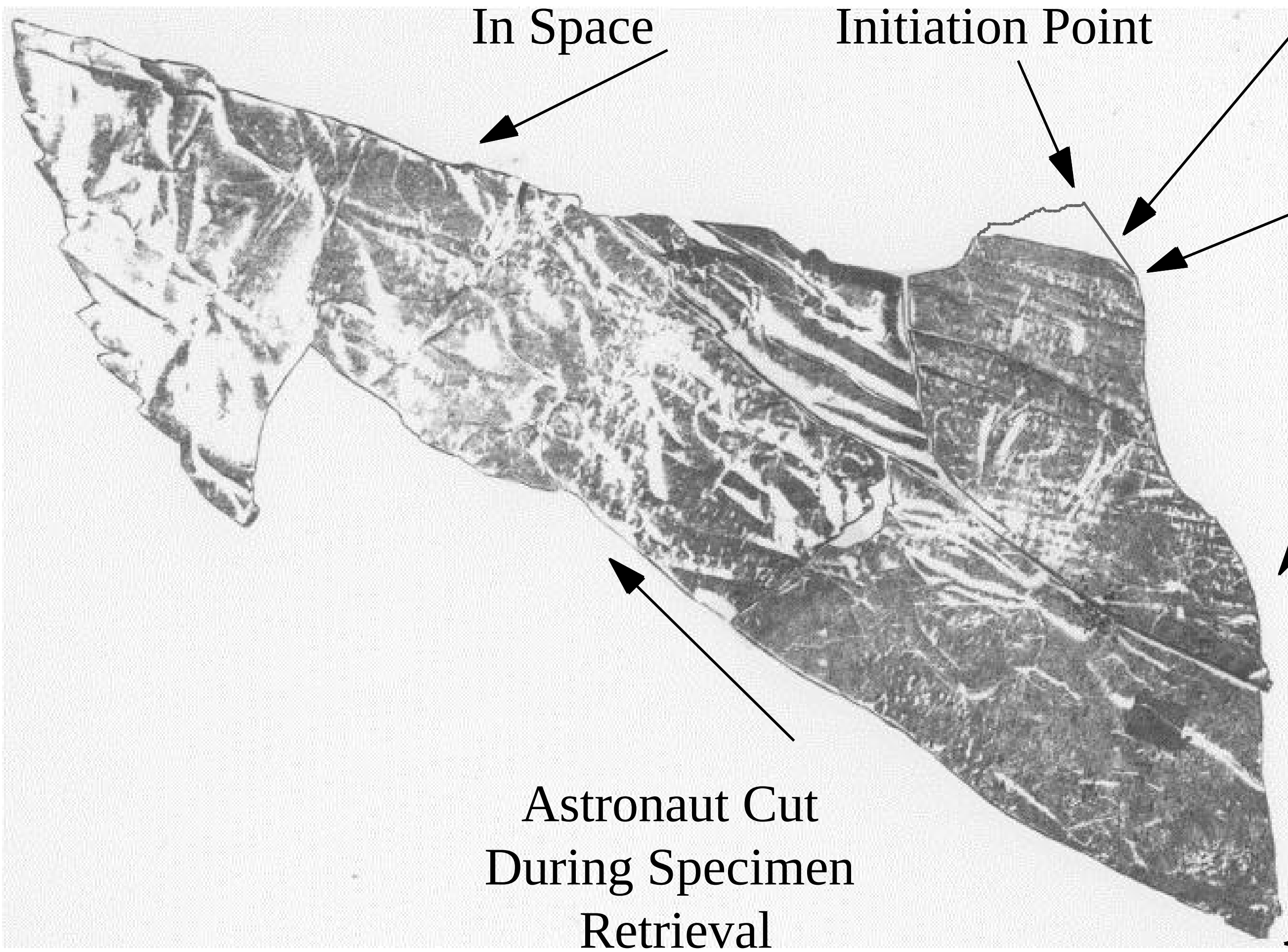
SM2 Light Shield (LS) Specimen



HST Observations

- Multi Layer Insulation Cracks
  - SM1: obvious damage only on anti-solar side
  - SM2:
    - more than 100 obvious cracks
    - severe cracking on both solar and anit-solar side
    - some cracks curled
- Silver Teflon Tape on radiator surfaces showed dark streaks

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Environmental Factors

- Radiation
  - Solar Exposure: UV, VUV, Soft X-rays (solar flares)
  - Trapped electrons and protons
- Atomic Oxygen: sweeping ram
- Thermal Cycling
  - Solar facing: -100 to +50 °C
  - Anti-solar side: -200 to -10 °C
- Synergistic Effects

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HST Orbital Environment

Sample	Equiv. Solar hr (ESH)	X-ray fluence (J/m^2)	Trapped electrons and proton fluence > 40 keV ($\#/cm^2$)	Plasma fluence ($\#/cm^2$)	Atomic Oxygen ($atoms/cm^2$)
SM1 MSS-A	11,339	0.5-4Å: 4.9 1-8Å: 74	electrons: 1.39×10^{13} protons: 7.96×10^{19}	electrons: 3.18×10^{19} protons: 1.11×10^{19}	1.56×10^{20}
SM2 MLI	33,638	0.5-4Å: 16 1-8Å: 252.4	electrons: 2.14×10^{13}	electrons: 4.66×10^{19}	1.64×10^{20}
SM2 CVC	19,308	0.5-4Å: 6.1 1-8Å: 96.9	protons: 1.83×10^{10}	protons: 1.63×10^{19}	

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Damage Mechanism Investigation

- Failure Analysis
- Simulated Exposures

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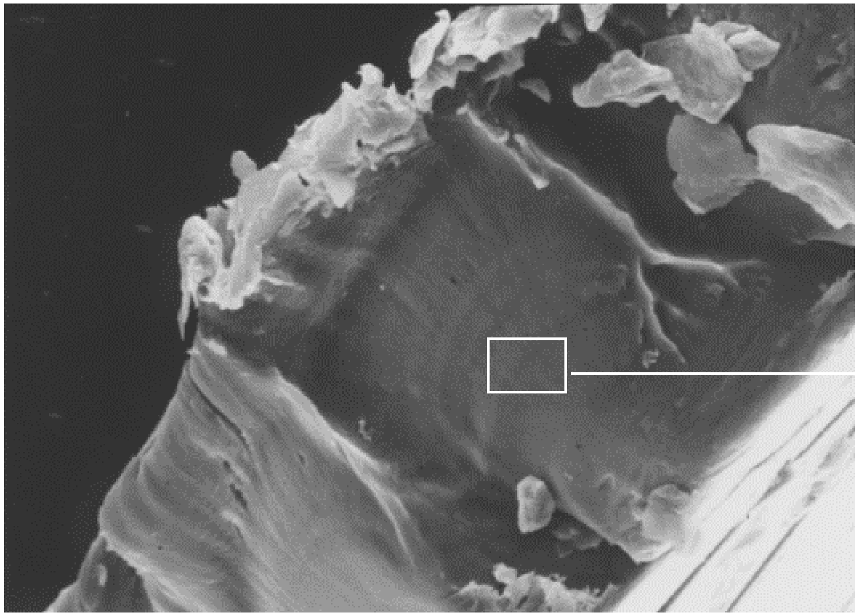
MLI Outer Layer Cracking (SM2)

Smooth Fracture (slow crack growth): created and propagated in space



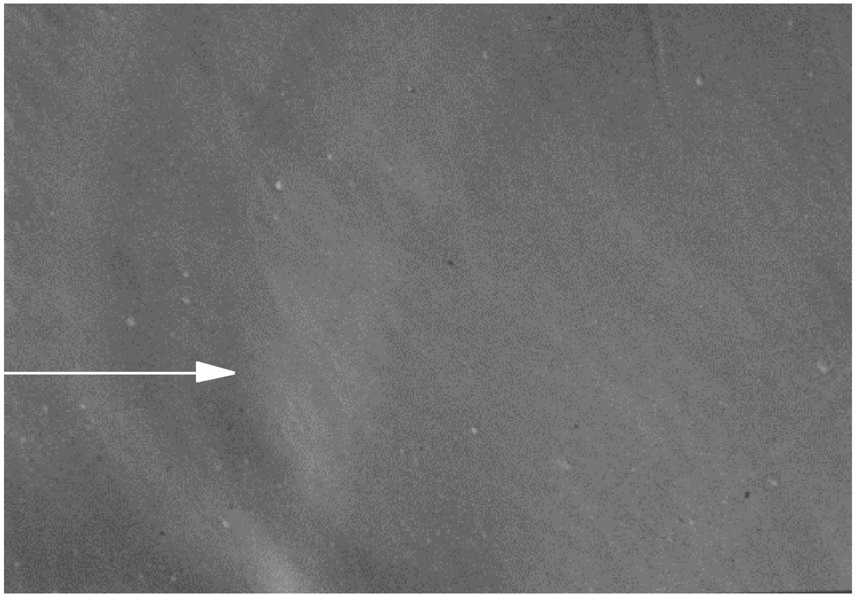


Image: Len Wang, Unisys/GSFC Materials Engineering Branch

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Vapor Deposited Metal Cracking

- Mud Tiling
  - > Homogeneous (random direction changes)
  - > Tensile cracks and buckling of metal
  - > ~10 µm x 10 µm up to 40 µm x 40 µm

Mud cracking/buckling of the VDA (LS SM2)

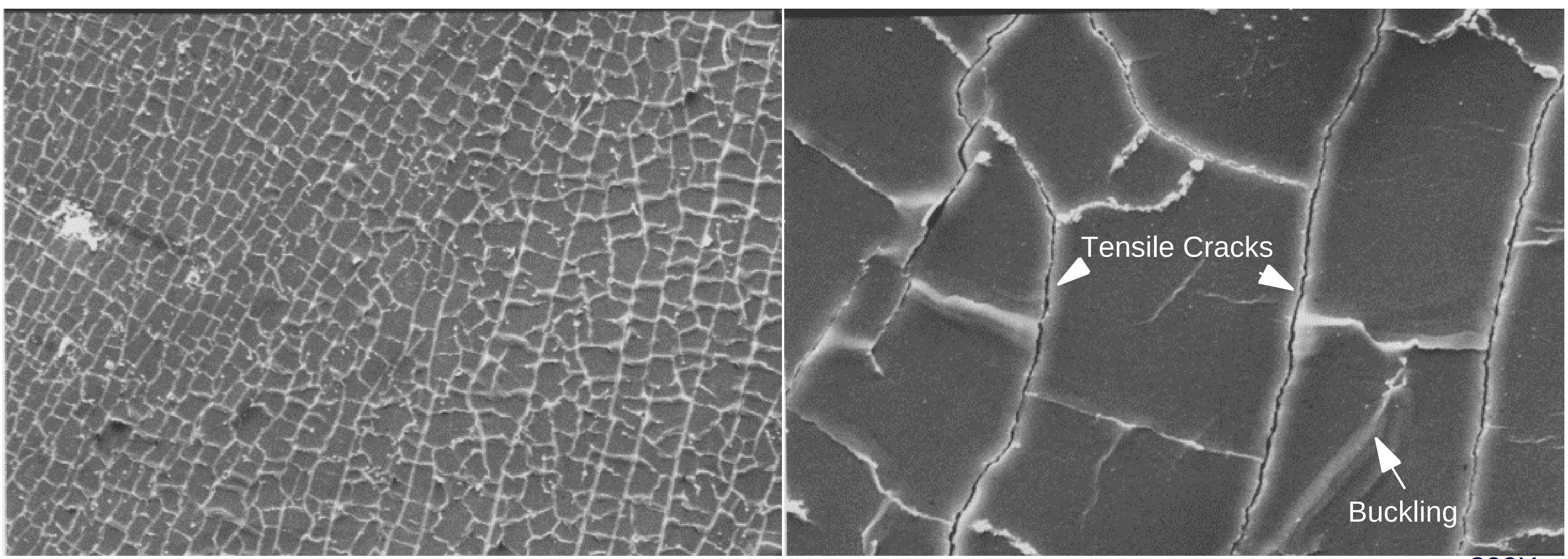

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Image: Len Wang, Unisys/GSFC Materials Engineering Branch

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Failure Analysis Summary

- MLI Outer Layer Cracking: Slow Crack Growth
  - Slow propagation; low stress; environmental factor
- Vapor Deposited Metal Cracking
  - Unsupported MLI: Thermal cycling; small α effect
  - Bonded CVC: Application; large α effect from adhesive
- FEP Damage: chain scission; increased crystallinity
  - Bulk embrittlement
    - Elongation: Pristine = ~350%; SM1 = ~150%; SM2 = 0%
  - Caused most of α increase by SM2 α
    - Absorptance: Pristine = 0.125; SM1 = 0.17-0.26; SM2 = 0.196
  - No crystallinity increase in SM1 specimens

Simulated Environmental Exposures

- Synchrotron Soft X-ray and VUV Exposure Brookhaven National Laboratories
  - High flux, narrow energy bands
  - 69 to 1900 eV
- Electron and Proton Exposure and Rapid Thermal Cycling
  - HST mission-equivalent fluences of 0.5 MeV electrons and 1 MeV protons
  - Thermal cycled: -100 to +60 °C; 15 second cycles

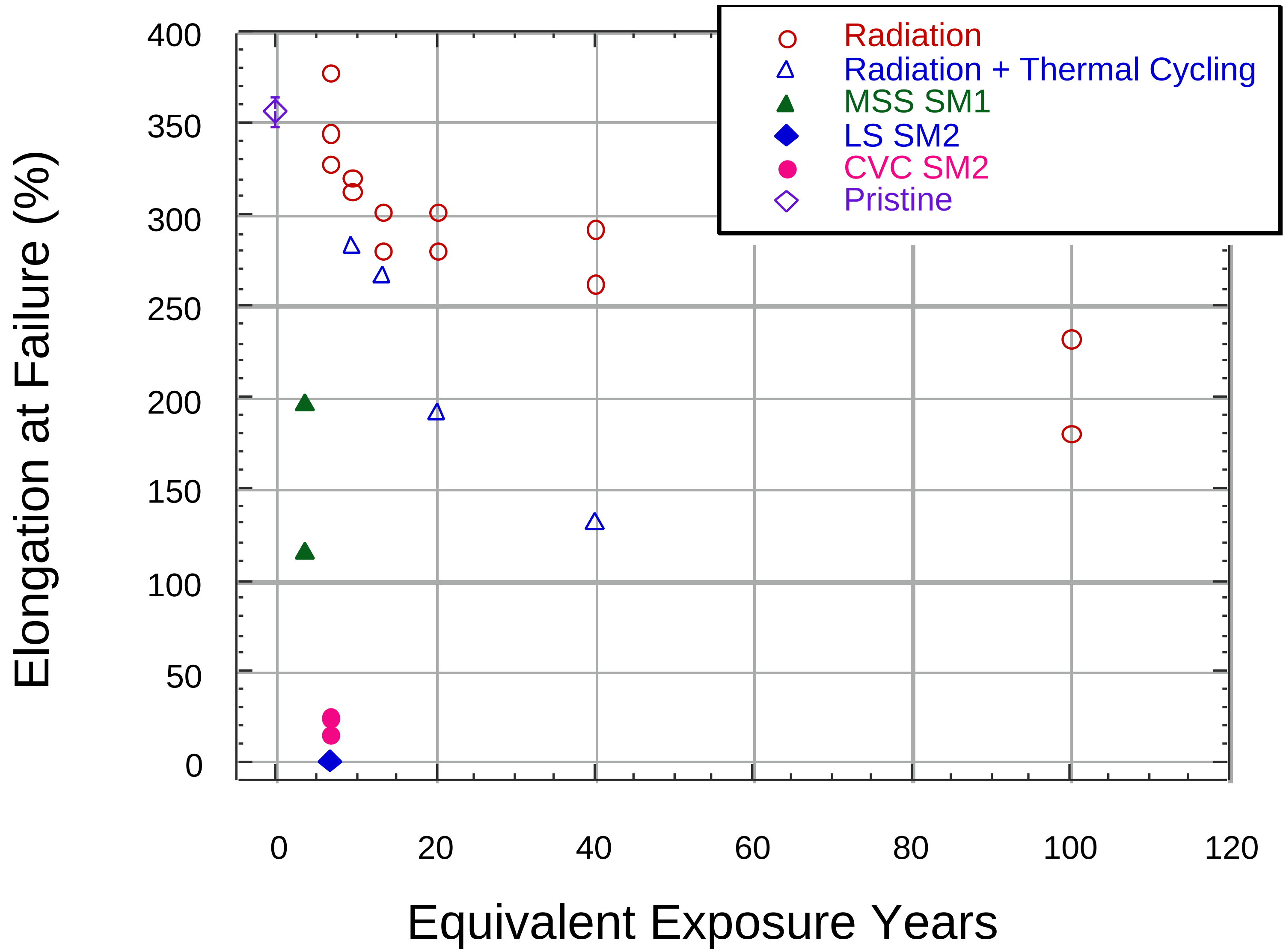
VUV and Soft X-ray Exposure

- Damage at very high fluences
  - 137 times EOL fluence at 1489 eV => 83% loss in elongation
- Negligible damage at HST fluences
- VUV and soft x-ray (69 to 1900 eV) alone insufficient to cause observed damage to HST

Electron and Proton Exposure and Rapid Thermal Cycling

- Damage not as severe as HST at SM2-equivalent exposure
- HST EOL (20 year) exposure yielded 46% elongation loss
  - Initial elongation: ~356 %
  - After radiation: ~290 %
  - After added thermal cycling: ~190 %
- Conclusions:
  - Electrons and protons reduced elongation and ultimate strength
  - Additional thermal cycling reduced elongation and ultimate strength

5 mil FEP/VDA: Electron/Proton and Thermal Cycling Elongation at Failure vs. Exposure Duration



Damage Mechanism Summary

- HST Observations:
  - SM1: Limited, localized cracking of 5 mil FEP on both solar and anti-solar sides
  - SM2: Significant cracking on both sides
- Failure Analysis of Returned Specimen
  - Cracking is a form of slow crack growth
  - FEP damage: chain scission, increased crystallinity
- Environmental Exposures
  - HST fluence of VUV/ soft x-ray alone insufficient
  - HST fluence electron and proton + thermal cycling significantly reduced elongation

Damage Mechanism

- Cracking Mechanism:
  - Thermal cycling with deep-layer damage from electrons and protons
  - Damage increases with combined total dose of UV, X-rays, electrons, protons and thermal cycling
- Solar absorptance affected by FEP degradation and VDS flaws (significant increase from adhesives)

Replacement Material Selection

- Candidate Replacement Materials
- Test Environments
- Selection

Candidate Replacement Materials

- Select replacement material with 10 year life
  - FRB prioritized 9 performance criteria:
    - solar absorptance/emittance requirements
      - at 10 years $\alpha/\varepsilon \leq 0.28$
    - maintain mechanical integrity
  - FRB rated each suggested material on anticipated performance in established criteria
  - 17 suggested materials pared down to six candidates

Candidate Replacement Materials

10 mil FEP/VDS/Inconel/adhesive/Nomex scrim

5 mil FEP/VDS/Inconel/adh/fiberglass scrim/adh/2 mil Kapton

10 mil FEP/VDA/adhesive/Nomex scrim

5 mil FEP/VDA/adhesive/fiberglass scrim/adhesive/2 mil Kapton

5 mil FEP/VDS/Inconel/adhesive/Nomex scrim

5 mil FEP /VDA/adhesive/Nomex scrim

OCLI multi-layer oxide UV blocker/2 mil white Tedlar

5 mil Teflon FEP/VDA (the current material)

$SiO_2/Al_2O_3/Ag/Al_2O_3$/4 mil stainless steel

Proprietary Teflon FEP/AZ93 White Paint/Kapton

Test Environments

- Sequential exposure to combinations of
  - electrons/protons
  - thermal cycling
  - ultraviolet radiation
  - atomic oxygen
  - soft x-rays
- Four candidate material sets exposed
  - Dose/fluence based on 10 year HST environment
- Two sets of current material exposed
  - Dose/fluence based on 6.8 year HST environment
  - Calibration/Control

Test Environments

Set	First Exposure Location	Electron Exposures: Duration (years)	Electron Exposures: Type	Electron Exposures: Energy (keV)	Proton Energy (keV)	AO (years)	X-ray (years)	Thermal Cycles: #	Thermal Cycles: Load	UV (ESH)
M1	MSFC	10	Dose	50 to 500	700	10	-	20,000	taped	-
M2	MSFC	10	Dose	50 to 500	700	-	10	3,200	taped	505
M3	MSFC	6.8	Dose	50 to 500	700	6.8	-	20,000	taped	-
B1	Boeing	10	Fluence	40	40	-	10	1,000	spring	-
B2	Boeing	10	Fluence	40	40	-	-	-	-	-
B3	Boeing	6.8	Fluence	40	40	-	-	-	-	-
L1	LeRC	-	-	-	-	-	-	>1500	mass	-
G1	GSFC	-	-	-	-	-	-	-	-	374
						MSFC	LeRC			GSFC

Selection

- Candidate performance documented following exposures
  - Absorptance
  - Crack Type/Extent
- Candidates scored and ranked according to original performance criteria
  - Included FRB member scores for each criterion
  - Score for given criterion weighted

Final Ranking of Candidates

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5 mil FEP /VDA/adhesive/Nomex scrim

10 mil FEP/VDA/adhesive/Nomex scrim

5 mil FEP/VDA (the current material)

10 mil FEP/VDS/Inconel/adhesive/Nomex scrim

5 mil FEP/VDS/Inconel/adhesive/Nomex scrim

5 mil FEP/VDS/Inconel/adh/fiberglass scrim/adh/2 mil Kapton

OCLI multi-layer oxide UV blocker/2 mil white Tedlar

5 mil FEP/VDA/adhesive/fiberglass scrim/adhesive/2 mil Kapton

Two ruled out prior to ranking for other considerations

Replacement Material Summary

- Selected Material
  - 5 mil FEP/VDA/adhesive/Nomex scrim
- Simulated Environments and Evaluation
  - Test plan produced cracks similar to orbit
  - Results vendor specific

Conclusions

- Minor damage to unsupported 5 mil FEP at 3.6 years
- Damage Mechanism
  - Unsupported films: slow crack growth
    - electrons/protons with thermal cycling ; UV, VUV, X-rays add
  - Tapes: application techniques
    - metal backing cracked; UV darkened adhesive
- Replacement Material
  - No FEP alternatives; need low α, radiation resistant thin films
  - Need UV stable adhesives
- Effects of LEO radiation on outer layer materials must be considered in design

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Appendix: Candidate Replacement Material Performance

- Solar Absorptance measured after each exposure
  - Exposure Correlation:
    - Largest change following thermal cycling of electron/proton/AO exposed specimens
  - Candidate Ranking:
    - Specimens with VDS had greatest increase
- Crack Propagation Types
  - Cracks comparable to orbital damage produced (slow crack growth 1)
  - Other types of cracking observed:
    - Tensile overload, slow crack growth 2, combination
  - Exposure Correlation:
    - Cracks propagated only during thermal cycling of exposed specimens
    - Cracks most like HST following 20,000 thermal cycles of electron/proton/AO exposed specimens
- Crack Extent
  - Mechanical integrity: Crack Extent
    - Crack Length not used because of scrim
  - Crack Extent Characterization
    - Number of scrim fibers passed
    - Delamination
    - Length
  - Candidate Ranking
    - Fiberglass scrim candidates poor
    - 10 mil candidates better than 5 mil